Eco-designing Product Service Systems by degrading functions while maintaining user satisfaction

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1. Introduction

The international community promotes and claims sustainable development practice. Besides social and economic aspects, environmental issues are incorporated to reach Factor X impact reduction objectives (Reijnders, 1998). Customers are growing aware of the environment when buying products and services. Indeed, initiatives from international organisations such as the OCDE (2002), UNEP (2009) and other NGOs, concerning responsible consumption, are being developed. Transition to more environmental friendly economic growth requires broadening our vision of products and services in a system perspective. Designers have to improve, and even more often, propose innovative solutions to satisfy clients and abide by regulations and standards pushing environmental performances associated with products and services. Eco-design is encouraged through European regulations like EPR (Extended Producer Responsibility), REACh (Registration, Evaluation and Authorisation of Chemical substances), WEEE (Waste of Electrical and Electronic Equipment) and ErP (requirements for Energy-related Products).

During the last decade, eco-design has been principally based on standards, mainly from the ISO14000 series, concerning environmental impact assessment and eco-design. Development has been based on the use of different tools associated with the Life Cycle Assessment (LCA) method and design process as recommended by the ISO standards. It is necessary to move further into the designing process by integrating other concepts, such as Product Service Systems (PSS), and to consider a systemic view of products and services. Designers and developers must be prepared to change paradigms. This article proposes one such change where designers consider degrading product and service characteristics as a possible means to improve environmental performances and a trigger for innovative solution.

It would not be the first time that industry considers products or service degradation to meet customer or industrial needs. Although dealing with lifetime rather than customer value, Joseph and Tang proposed sacrificing quality at the initial stage of the product's use, to improve the reliability of the product and increase time-to-failure. The proposal was applied to a theoretical case concerning the diameter of the balls in roller-ball bearings (Joseph and Tang, 2007). Another example came from the ICT sector. Degrading transmission quality was necessary to boost the diffusion of video services. Formerly, video diffusion had been costly and mass diffusion technically unfeasible. To produce real-time video applications, such as video teleconferencing, it was necessary to transmit large quantities of data. To satisfy more clients, developers had to dramatically reduce the bandwidth of the video data. As a result, applications for viewing videos were rapidly available in high technology devices like computers and mobile phones. At the beginning the quality was degraded to meet needs. Later, designers improved image quality, for example, by adapting perceptual video quality control mechanisms based on application-level perceptual video quality schemes (Lu et al., 2002). Today, technical performance degradation could become an innovative motor to reduce environmental impacts.

Bearing this in mind, this article integrates approaches that accelerate the process and help designers innovative in eco-design through degradation. Designers have to combine environmental aspects and knowledge of the customers to maintain acceptable performance of the offer. They should identify the system of products and services, and not just the product, to understand customer needs and expectations and their evolution over time; analyse their offers more deeply; concentrate on the final,

delivered services; understand user perception of the overall system; evaluate true user expectations and be ready to negotiate product and service characteristics and performances with their clients. The principle proposed in this paper is close to value engineering (Miles, 1961). The problem at that time was post-war mass production at acceptable cost in a situation of insufficient extraction of raw materials, while today, satisfying customer demands of quality is more exigent and especially subject to greater environmental stress.
In section 2, this article proposes substitution of functions in products and/or services as a key to proceed to degradation. Section 3 uses environmental and economic tools to negotiate technical performance degradation of a product or service. In section 4 a case study of electronic environmental sensors is presented. This case illustrates how developers combine different approaches to facilitate the eco-design process. Section 5 discusses the results and provides perspectives.

2. Innovative Approaches to Product Service Systems

This section underlines how concern for environmental impacts of goods and services encourages the move from products to PSS while good eco-design imposes appropriate definitions of functional units that support innovative product-service combinations. Economically, efforts to optimise cost and materials lead to the consideration of customer needs and expectations. In particular, value engineering opens the way to introduce customer satisfaction and correctly substitute functions. In the context of PSS, functions are provided by combinations of products and services and so substituting functions means modifying these combinations and substituting products and services. The section suggests that creative thinking may guide substitution in solutions that, although they degrade technical features of the PSS, maintain overall performance and, particularly, user satisfaction.

2.1 Product Service Systems

In the market, customers can be offered several options (in this article the customer, client or consumer is a person who uses the product or service). They could simply buy a product, a pure service or get a combination of products and services. Changing paradigms requires moving the frontier between products and services (Sakao et al., 2006). For a long time, enterprises focused on mass production and selling physical products with environmental consequences related to material transformation (Maussang et al., 2009). Nevertheless, it was observed that the increase of the consumption of material goods does not necessarily lead to the increase of the quality of life (Tukker, 2005). Therefore, many developed countries have tried to decouple economic growth from environmental pressures. One way to achieve that was to switch from a product-based economy to a service-based economy by moving towards a new economical model (Maussang et al., 2009). Several concepts have emerged, for example, PSS (Tukker and Tischner, 2006), functional economy (Bourg and Buclet, 2005), total care products (Alonso-Rasgado et al., 2004), service engineering (Sakao et al., 2007) and extended products (Thoben et al., 2001).
According to Maussang, some companies switch to a ‘partial’ service economy in order to stand out from competitors and earn more money. Most of the time, support and maintenance services are added to physical products (extended warranty, availability of parts and so on). They provide new value to the products sold. However this is not a systemic change to the economic model because it often only brings incremental innovation to products and not a complete change in the manner to develop the system. In fact, the products and services are simply modified, based on existing ones (Maussang et al., 2009). In the future, designers will be asked not only to improve a product or service, but to move further and switch from the original product or service to other products, or services, or a combination of them, so as to minimise material flow and transformation. They may even propose new strategies using the initial products or services to satisfy the clients.
The PSS concept emerged from a new sales approach where the customer no longer pays to own the product but rather pays for a use, result or functionality provided by a system (Maussang et al., 2008). Tan et al. (2007) defined the PSS as “innovation strategies where instead of focusing on the value of selling physical products, one focuses on the value of the utility of products and services throughout the product’s life period”. It is necessary to consider the value provided by the PSS. The idea is to

provide features or produce results with a PSS instead of a physical product alone (Maussang et al., 2009). What is more, Maussang suggested that from an external (customer) point of view, there would be no more borders between the products and the services of the system.

Car-sharing systems are a good example of PSS. Such systems have been set up by associations such the Citélib system in the Rhône-Alpes Region in France, or private companies such as the German systems ‘Mietermobil’ in Wolfsburg and ‘Wonh mobil’ in Hamburg (UNEP, 2011). Basically in these systems, owning a physical object (car) is replaced by the service of being given access to an individual transport system whenever required. The user easily picks up a car whenever necessary and generally pays per use. The PSS concept emphasises that users do not always need to possess objects. They can be satisfied simply by the service that the objects support and the results they obtain. This opens the possibility for designers to propose new solutions to clients with lower environmental impacts. This means that designers need to deepen their understanding of client expectations and satisfaction and adapt functionality of the offerings to changing customer expectations over time.

2.2 Identification of a Functional Unit to Support Eco-innovation

For 20 years, LCA has been widely used in environmental assessment and more recently in eco-design and eco-labelling processes. Amongst other advantages, it helps designers to cultivate life-cycle thinking and possibly avoid the transfer of environmental impacts from one impact category to another or from one life-cycle stage to another. LCA facilitates the reduction of environmental impacts by providing information, indicators and diagrams to establish environmental profiles of the products. It is useful for comparing, improving, innovating and eco-designing products and the associated production processes. Different approaches, based on LCA, have been used to support the eco-design of PSS (Lelah et al., 2011).

Eco-design relies on the Functional Unit (FU), defined by the ISO14040 standard. The purpose of the FU is to provide a reference to which the inventory data are related. The FU is a representation (model) of the service obtained and then perceived by the users of the product (or service). The FU is a useful tool for comparing products, services or a combination of them.

Nevertheless, it is not always easy to identify what the delivered service and its perception by the user is, neither to represent it in a FU. Cooper (2003) studied the issues concerning the choice of the right FU for a product. One difficulty is that the function of a product is rarely one-dimensional and strict measurement of the primary function covers only a part (although relevant) of the comprehensive set of functions (Frischknecht, 1997). Furthermore, the boundary between quantifiable and unquantifiable functions is not obvious and cannot objectively be drawn (Frischknecht, 1997). Finally, the definition of the FU and reference flows can be difficult due to issues related to the life span (affected amongst others by customer habits), performance, system dependencies, product alternatives, functions, features in addition to the principal one and other factors (Cooper, 2003).

By defining the FU, designers have to systematically analyse the functions of the product and the associated processes. They must sharpen their knowledge on the products, associated services, supply chain, processes and also the clients. The functions will often be quantified by physical measures, for example, a rate of failure, but they also cover subjective values of client satisfaction that are qualitative. For example, Wenzel et al. (1997) stated that a qualitative description must define a quality level for each function that facilitates comparisons. Cooper, (2003), recommended that the service must be experienced as comparable by the user with respect to both the quantitative and qualitative characteristics. The quantitative and qualitative functions mentioned in literature should be brought into the definition of the FU and considered as additional technical information during the interpretation phase and related decision making process. Frischknecht, (1997), proposed a panel in which decision makers and stakeholders set the FU and the analyst defines and evaluates models to match the goals and FU defined. A second method he suggested, for the reference flows, was to define comparable functions in terms of what is accepted as comparable in the market place. For example, the FU could be defined on the basis of which products the consumer conceives as equivalent substitutes. Other authors have highlighted the importance of considering not only the quantitative properties of the

products/services in this analysis but also the qualitative ones (Cooper, 2003) and (Ruhland et al., 2000). All these solutions represent keys for designers concerning knowledge and innovation.
In conclusion, the difficulties associated with the search of an adequate FU for eco-design provide an opportunity for designers to improve their representations of the product and services. This can become a motor for the eco-innovation processes and facilitate the research of substitute goods that represent the same level of service utility for users (Ryan, 2000). This means that if designers identify sets of products or services representing identical satisfaction for users, they may then propose solutions using really different products and services with less environmental impacts but still fulfilling users' expectations.

2.3 Client Needs and Satisfaction

It is necessary to understand how customer needs and satisfaction would affect the design of PSS. User experience design in industry seeks to "improve customer satisfaction and loyalty through the utility, ease of use, and pleasure provided in the interaction with a product" (Kujala et al., 2011). Customer needs are established in the customer domain and formulated in the functional domain as a set of functional requirements (Tseng et al., 1997), which are then used to orientate design of the offering (Maussang et al., 2008). The term can reflect needs that the customer faces during his occupations and are part of the main reasons why the customer initially turns to the offering. However, when using the product or service, other needs may arise from the way the customer experiences use, involving, for example, the quality of the offering. The customer measures quality in terms of factors that include achieving functional requirements and one of the issues involved in the design process concerns identifying real as opposed to perceived needs of the customer (Sivaloganathan et al., 1995). However the perceived quality of a product is not so widely documented in literature, although customer perceptions have been studied through customer satisfaction (Nepal et al., 2006). Notably, customer satisfaction must be considered over time as relations between the provider and customers change (Kujala et al., 2011). In this paper we will use the term perceived service to cover the perception or experience by the customer of the PSS offer.
Value engineering was first developed by Miles (Miles, 1961) after World War 2 when many materials used in industry were difficult to obtain (Elias, 1998). It seeks to deliver whole life performance and cost without deteriorating quality and uses functional analysis to integrate customer needs as the basis of value analysis in value engineering (Male et al., 2007). Using rigorous methodology facilitated the understanding of complex systems by converting activities performed in a system to the functions performed by the system for its customer (Bartolomei and Miller, 2001).
In PSS, the main function is decomposed into technical functions that are then detailed into technical solutions (Maussang et al., 2008). PSS design methods include forms of customer representation. For example, PSS blueprinting, focusing on customers (Geum and Park, 2011), or on supply-chain partner needs (Lelah et al., 2012), has been adapted from Service Blueprinting (Shostack, 1982). These tools describe the relations between customer activities and other activities related to products or hidden services. The level of details of the activities provides the designer with a representation of what the customer actually perceives. Shimomura integrated the design of services and products in order to maximise customer value, proposing a unified representation of human and physical processes in service activity. The change of state for a customer is expressed by a Receiver State Parameter representing customer value (Shimomura et al., 2009).
Utility theory (Mas-Collel et al., 1995), specifically introduced a measure of customer satisfaction. Utility is a mathematical representation of preferences over a set of products and services. Preferences can be modelled as long as they are mathematically transitive, complete, and continuous. Utility cannot be measured or observed directly, so economists may infer it through relative utilities from observed choices. In theory utility can be plotted in an N-dimensional space (Figure 1 shows a 2-dimensional space), with indifference (iso-value) graphs. It displays the combination of commodities (quantities represented in the X and Y axes) that a person (or a society) would accept while maintaining a constant level of satisfaction. In Figure 1, users experience the same level of satisfaction on $\boldsymbol{A}$ or $\boldsymbol{B}$. They are

indifferent to this change. In ***C*** and ***D***, they experience a higher level of satisfaction (utility) but they are indifferent to changes between ***C*** and ***D***.

Figure 1. Utility graphs for two products.

Ryan (2000) pointed out the importance of meeting consumer needs through the utility of product ownership to a system designed to deliver equivalent utility.

All these approaches insist on the importance of identifying the different aspects of the system proposed, their relationships and their intermediary and final functions in order to improve knowledge of the service expected by the user and evaluate his perception of the service. They argue for maintaining client satisfaction when switching functions.

2.4 Discussion

Finally, it is clear that the substitution of products or services is not a new concept. Economic sciences have previously recognised that there are products that can be considered as substitutes. PSS encourages the substitution of material products by services (Ryan, 2000). However this implies system innovation and indeed, PSS have been defined as innovative strategies, shifting the business focus from products to a system of products and services (Manzini and Vezzoli, 2003; Tan et al., 2007). Furthermore, sustainable development requires systemic innovations in a holistic framework (Boons et al., 2013) that focuses on the PSS solution and its value chain, as well as contextual conditions (Ceschin, 2013). This means extending existing solutions and exploring new alternatives, changing the mindsets of designers and clients. The ability to shift sustainability goals will help craft new value propositions and adapt product design, influencing the market performance (Keskin et al., 2013). Designers must displace current frontiers between products and services and break away from representations of systems even though they seem to work today. Creative methods have effectively been combined with LCA in the past to design eco-efficient products (Sakao, 2007). They can therefore be used to support a systemic approach that should cover both products and services in the offering.

Further on in this paper we orient innovation more specifically towards the substitution of functions provided by the PSS to improve environmental performances.

3. Degrading Process

The previous sections suggest that degrading the PSS could offer the possibility of reducing its' environmental burden. However, the final perceived service would be affected by degradation. To improve the environmental performance of a PSS it is necessary to understand how degradation affects the final service. Negotiation with the customers is necessary to determine the compromise between the service and environmental performance. In this section, an iterative method for determining such a compromise is conceptualised.

3.1 Degrading PSS Functions

This article advocates that to improve environmental performances, designers should innovate and study the possibility of partially degrading the PSS. For this, it is first necessary to identify the internal and external functions that are fulfilled by the different PSS parts (Maussang et al., 2009). External functions can be considered as the set of final services that the users actually perceive, while internal, or intermediary functions, concern the correct operation of the PSS without being directly perceived by the user. For example, in a car sharing PSS, the user does not necessarily care how the car got to the pick-up spot (internal function); as long as it is available at the right time (external function).
Delivered service should match user needs. Here again it is important to distinguish final and intermediary needs. In the car sharing example, to use the car, the user may need a magnetic card to start the car but this intermediary need does not directly satisfy the user's final need for car-transport.
However, perfect matching of needs is ideal and it is often difficult to completely match users' expectations, so delivered services would be over-dimensioned. This could mean that the PSS integrates over-dimensioned parts (product or services). Consequently, it uses more components, processes and materials, with more environmental impacts. The PSS would not be optimal.

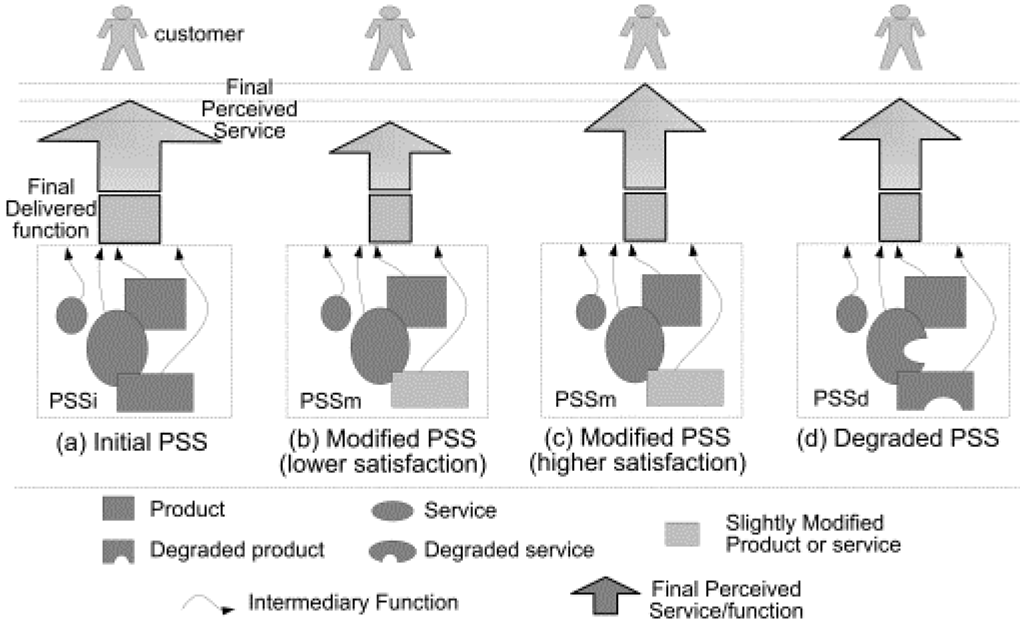

Figure 2. Effects of Modifying or Degrading a PSS Solution.

Figure 2 conceptualises the process. 2(a) represents an initial PSS solution with physical objects and service units (see Maussang et al., 2009) and the user interface. Thin arrows represent intermediary functions that help run the PSS. Users do not necessarily perceive these intermediary functions directly but they are needed to deliver the final functions represented by the shaded box above the PSS boundary in the figure. The width of the box represents the number of final external functions offered. The arrow stemming up from these final functions represents user perception. User perception is related to real needs and expectations that are not necessarily what the designers imagine and is represented by the arrow's height.
Notwithstanding the quality or the quantity of the functions provided (the width of the arrow), in fine, it is the perceived customer satisfaction, including satisfaction of the quality of the PSS, (the height of the arrow) that is important. Just as "value engineering is not […] a method for reducing costs through degrading performance" (Elias, 1998), the idea here is to consider degrading some parts of the PSS, without modifying user perception of the PSS nor final, long-term, satisfaction. This does not mean that the PSS does not work correctly or is unreliable. That is why it is important to consider overall, long-term satisfaction. By correctly characterising the PSS, designers may analyse possibilities of degrading or removing some intermediary technical functions. Back to the car sharing example, in the case of electrical cars in the city, intermediary functions could include insuring a certain battery-level before

reuse. This could be ideally checked systematically after every use of the cars, but could also depend on reservation times for future use.
User satisfaction must be evaluated in some way and even if it can neither be measured nor observed directly, it must, at least, be appreciated through observation of consumer choices and preferences.
Degradation means that some of the delivered functions are not optimized for performance individually. The user can be aware of this or not, but in any case, it must not be prejudicial to the user. The type of degradation will depend on each PSS. The degradation can be applied to products (mass, material performance, aesthetics, etc) or to services (frequency, information etc).
Degradation is illustrated in Figure 2. The initial PSS (a) is modified (b, c) by reducing, or slightly modifying, the number of functions, resulting in degraded (b) or improved (c) satisfaction of the user. Correct degradation (d) of some of the product or service elements does not finally diminish overall user perception of functionality and consequent satisfaction.

3.2 Negotiating Functions

To eco-design PSS, reducing environmental and health impacts while simultaneously keeping clients satisfied, it is necessary, not only to have better knowledge of the consumers, but also to identify the possibilities and the means of negotiating PSS characteristics with them. Negotiation here means that different sets of characteristics will be perceived differently by customers, and the purpose of negotiation is to determine the best compromise between customer satisfaction and environmental performance of the PSS.
After negotiation of a set of characteristics, PSS functions are determined and the corresponding PSS structure is proposed. The environmental impacts are then evaluated using LCA or other methods. Customer satisfaction is evaluated at the same time. For the chosen characteristics of the PSS, different levels of customer satisfaction can thereby be associated with different levels of environmental impact. The level of precision depends on the design phase and understanding of customer satisfaction.
Figure 3, displays the principles in an ideal case, using just one environmental indicator. It supposes linear evolution of customer satisfaction and environmental impact to illustrate the concept simply. This is not necessarily the real case: practically the designer proposes a set of discrete solutions and customer satisfaction is often non-linear or noisy. However reasoning is similar and the best compromise between satisfaction and impacts may be chosen.

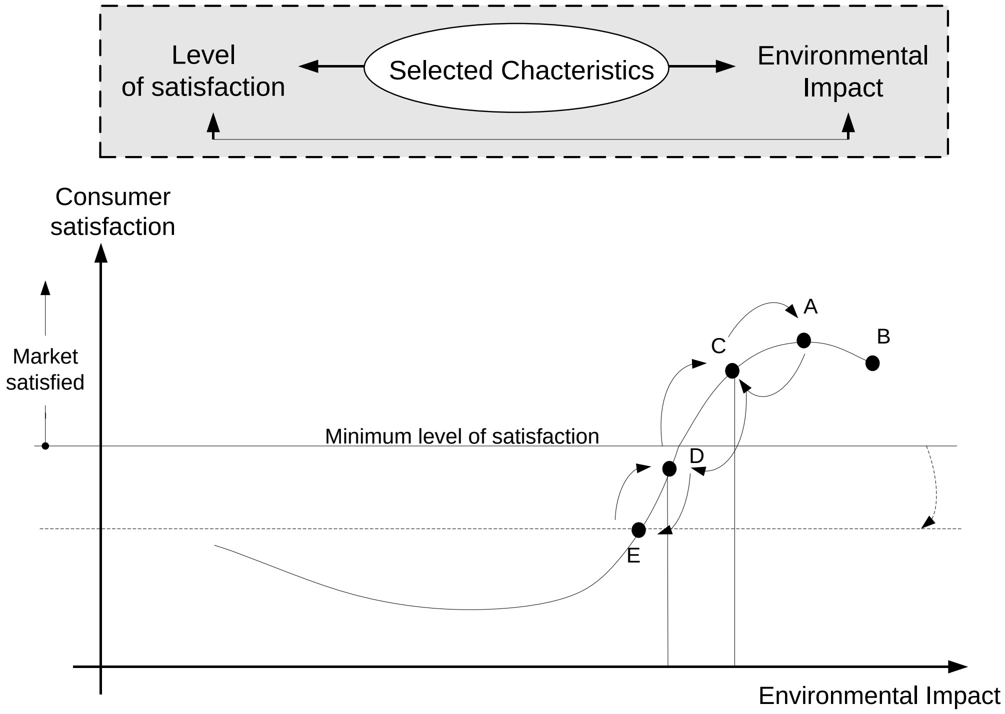

Figure 3. Consumer Satisfaction and Environmental Impacts for a Set of PSS Characteristics.

Figure 3 represents a negotiation process to reduce environmental impacts, while satisfying customers. The minimum level of satisfaction is represented by a horizontal line. If the original PSS is represented by ***A*** then reducing impacts would mean moving to ***C***. ***B*** provides similar satisfaction but induces higher impacts. In this one-dimensional case, to reduce impacts means moving towards the left on the impact axis. However, moving too far, for example to ***D***, implies that the users may be insufficiently satisfied. Nevertheless, in this case, the users remain close to the minimum level of satisfaction, which is not the case for ***E***, well below the acceptable user satisfaction level. Moving to ***D*** requires some form of negotiation. Reaching ***E*** will require a very good strategy of communication and negotiation.
To improve the environmental situation, it is necessary to consider renegotiation of the acceptable level of user satisfaction with better knowledge of final and intermediary consumer needs. This can be done directly or indirectly. A direct process means negotiation and convincing clients about environmental and other advantages. An indirect process means auto-reduction of expectations by the clients as they become aware about environmental and health problems. This evolution may be individual or collective (societal).
Similar reasoning is applied when more than one environmental impact is considered. Figure 4 illustrates the case of two environmental impacts.

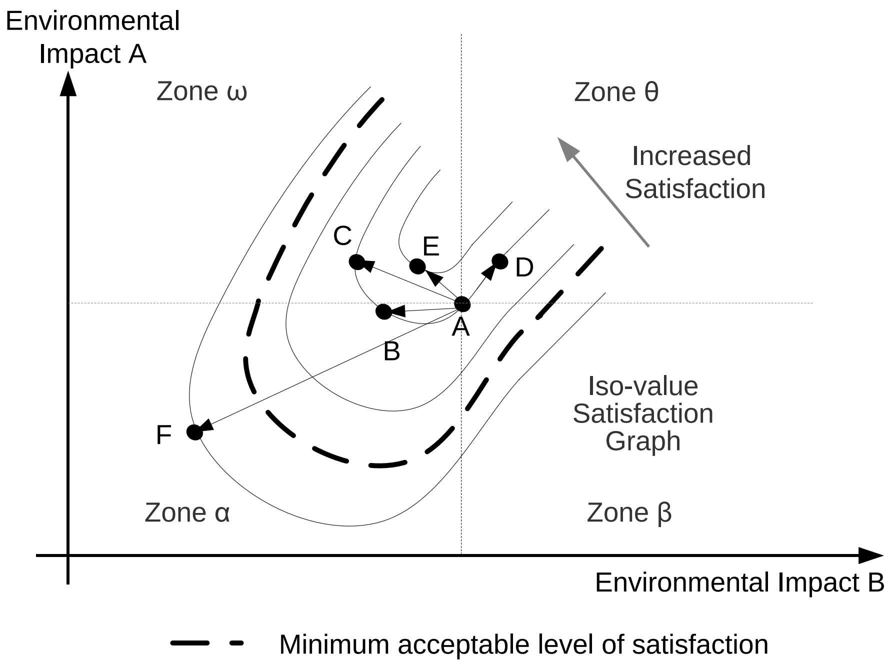

Figure 4. Iso-value Satisfaction Graph.

Here, for each set of functions provided by the PSS, an iso-value graph represents constant value or satisfaction. Starting from ***A***, to reduce environmental impacts means moving into ***zone α***. Movements towards ***zone θ*** mean worsening the environmental burden. Movements towards ***β*** and ***ω*** mean improving one environmental performance and worsening the other. The ideal situation is to move towards ***α***. Moving to ***B*** conserves satisfaction while improving all environmental impacts. Moving to ***C*** and ***D*** also keeps the customers satisfied but worsens at least one environmental aspect. Commercially, ***E*** represents the ideal situation since client satisfaction increases. Nevertheless ***E*** signifies a loss in one environmental performance. The dashed line denotes the minimum acceptable level of satisfaction. Moving to ***F*** requires negotiation to shift the minimum level of satisfaction.
Practically, it is necessary to analyse iso-satisfaction and environment performance simultaneously as shown in Figure 5.

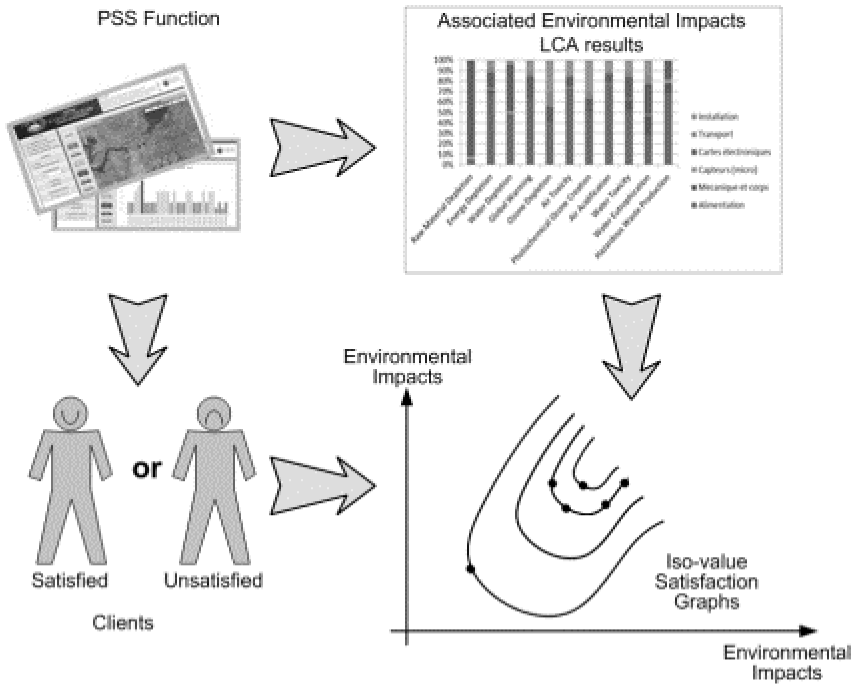

Figure 5. Environmental Impact Profile and Satisfaction.

The figure starts with le example of a PSS display function in the upper left-hand corner. Implementing the display function causes impacts to the environment that are shown here in the form of LCA results. At the same time the clients are satisfied or not by the display function. Comparing environmental impacts and client satisfaction for different implementations of the function will draw up iso-value satisfaction curves.

The techniques and curves can differ in different situations, depending on the context and the means that the PSS supplier is able to support, but in all cases the reasoning remains basically the same.

The next section describes how this is may be applied to degrading functions.

3.3 Iterative approach to degrade functions

An iterative process is used to explore possible PSS solutions and create a customer satisfaction vs. environment plot (Figure 6). Focus here is put on environment and satisfaction, but economical and other technical considerations can obviously influence the final decisions made.

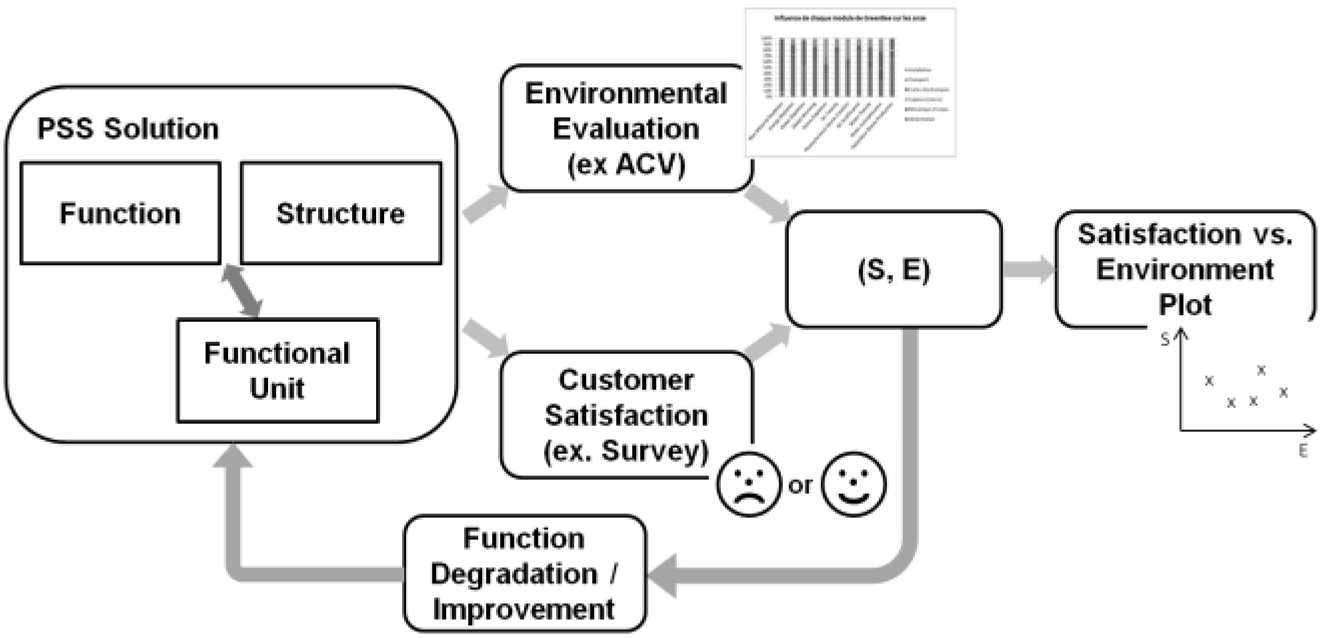

Figure 6. Iterations.

An initial PSS solution is characterised by its functions and structure, determined by functional analysis. The Functional Unit is determined. Following the grey arrows, two tasks are carried out for the solution: environmental analysis is performed to determine environmental impact, ***E*,** (this can be a simplified form of LCA) and customer satisfaction, ***S***, is determined (through a customer survey or based on commercial success). The couple ***(S, E)*** determines a point on the satisfaction vs. environment plot. For the initial solution there is as yet only one point on the plot. The possibility of degradation is then explored by the design team, using, if necessary, creative techniques, to propose new alternatives for the PSS solution. For each alternative solution, a new ***(S, E)*** couple is added to the satisfaction vs. environment plot. The process is reiterated as many times as necessary. Reasoning can be understood through the example in Figure 7.

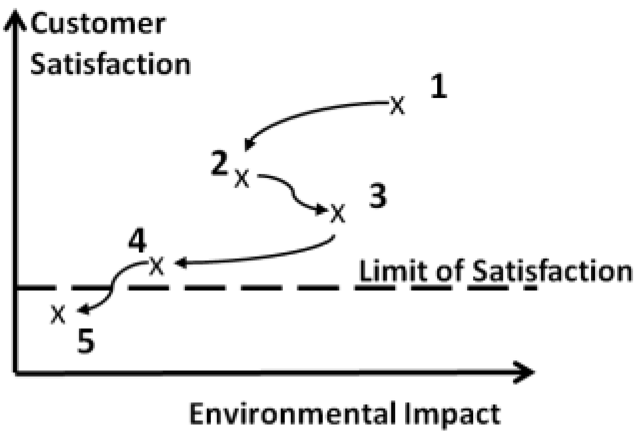

Figure 7. Example of Iteration.

Here, a fictive practical example is performed with 5 iterations. The initial solution, ***1***, is degraded to ***2***, which shows better environmental impact. Customer satisfaction is still positive. Further degradation, ***3***, increases environmental impacts and so a new direction is taken to find the point ***4***. Yet further degradation, ***5***, reduces customer satisfaction below the acceptable limit. In this case the solution ***4*** is finally chosen.

4. Case Study

Eco-design by degrading PSS characteristics while maintaining satisfaction will depend on each particular case. The following study illustrates how it is possible to learn and capitalise knowledge in PSS. The information is derived from interviews and close work done with Azimut Monitoring over the past few years.

4.1 - Context

Azimut Monitoring is a French Small and Medium Enterprise (SME) providing PSS offerings for environmental sensor applications. Sensor information is transmitted and formatted as services, while the sensors remain propriety of the SME. The SME constantly looks towards innovation and technical and environmental improvement of their offers. The clients are airport facilities, urban administrations, building facilities, etc. and are generally not environmental experts. They receive environmental information in the form of “pedagogical indicators”, concerning indoor or outdoor environmental conditions (noise, pollution, humidity and temperature). The SME provides coaching to guide and optimise the use of the information as well as regular reports.

Recently, the SME participated in a project seeking to provide a telecom infrastructure for monitoring solutions to optimise urban services. The infrastructure raised hopes as a sustainable solution for cities (Lelah et al., 2011). However, the deployment of large-scale networks involved large numbers of electronic equipments and was not without impact on the environment. The proposed PSS had therefore to be analysed and eco-designed.

4.2 Initial PSS Offer

System	Associated Product (Principal characteristics)	Associated Services	Principal Reason for Modification
Solution 0: Existing market sensors	Sensor measuring one environmental information	Transmission of raw data	
Solution 1: Prototype and services	Prototype Sensor measuring different environmental data (aluminium charter, shell, solar panel)	Data processing, Pedagogical indicators	Insufficient resources and know-how (client)
Solution 2: Ladybird®: Sensor + services	Industrialised Sensor (aluminium charter, shell, solar panel)	Data processing, Pedagogical indicators, Reports, Consulting	Energy consumption, Robustness, Industrialisation needs

Table 1. Initial Solutions.

Prior to the SME offering, clients had to buy and install devices measuring environmental data (generally only one kind of data) without any treatment. They had to process the information themselves (***Solution 0*** in Table 1). Very soon, the clients had problems linked to time, know-how and staff necessary to process ever-increasing quantities of data.
From the beginning, the SME found that what the client really needed was not so much to get environmental data, or the sensor, but simple indicators to make decisions. Therefore they designed a prototype that measured different environmental data. They then proposed a set of adapted indicators (***Solution 1***) to their clients. At that time, the designers noticed that to industrialise the product and avoid environmental impacts they had to reduce energy consumption and build a more robust device (***Solution 2***).

4.3 New PSS Offer with Degraded Technical Function Performances

With the new project, the SME had to go further in the eco-design process (***Solution 3***). Figure 8 summarises the process followed.

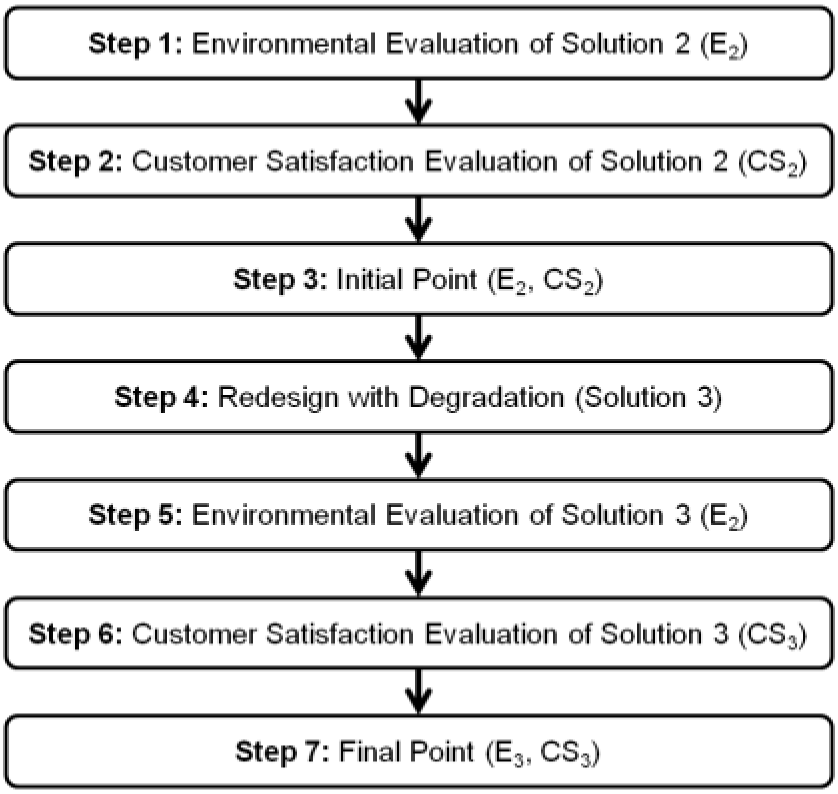

Figure 8. Iteration from Solution 2 to Solution 3

First, Solution 2 was evaluated, providing the starting point (***E_2*, *CS_2***) to redesign the PSS. System constraints were integrated and the functions were degraded according to experience gained in understanding the customer. The redesign came out with ***Solution 3*** that was evaluated, providing the final point (***E_3*, *CS_3***). The principal evolutions of this solution are summarised in Table 2.

System	**Associated Product (Principal characteristics)**	**Associated Services**	**Principal Reason for Modification**	**Principal Function Degraded**
Solution 3: Greenbee®: Sensor + services	Industrialised Sensor (plastic charter, reduced power, mechanical and electronic simplification)	Less data processing, Pedagogical indicators, Reports, Consulting	Energy consumption, Democratisation of information, Industrialisation, Cost, Maintenance considering environmental aspects of supply chain and end-of-life	- Less data collection, processing, transmission - Microphone with less functions

Table 2. New PSS Solution.

In this case, technical function performance degrading principally implied less data measurement and simple indicators rather than very precise data with technical potential that was unnecessary for the customer’s needs. For example, sampling noise at very high rates is not necessary in most applications. The major effect of degradation was therefore to lower the burden of transmission of data and thereby reduce the needs for power in the sensor module. This led to lighter batteries and more compact solar panels. The lighter batteries made it possible to move from aluminium casing to composite materials that had not been appropriate for earlier solutions for technical and economical reasons. To compensate the degradation of functionality, efforts were put into the commercialisation of a global system extending the initial services to include expert analysis and other personalised supporting services.

Figure 9 shows where the PSS was actually modified in order to degrade the technical performances of the functions whilst maintaining the final perceived services. Data sampling was reduced and the physical Azimut sensor redesigned. Although the potentials of final services were reduced, the effective services were maintained and the client display was not altered. In the figure the potentials of the final services represented by the width of the final function arrow had been diminished because the data sampling rate was lower. However the effective services were maintained (the height of the arrow) as, practically, the clients did not require such high rates.

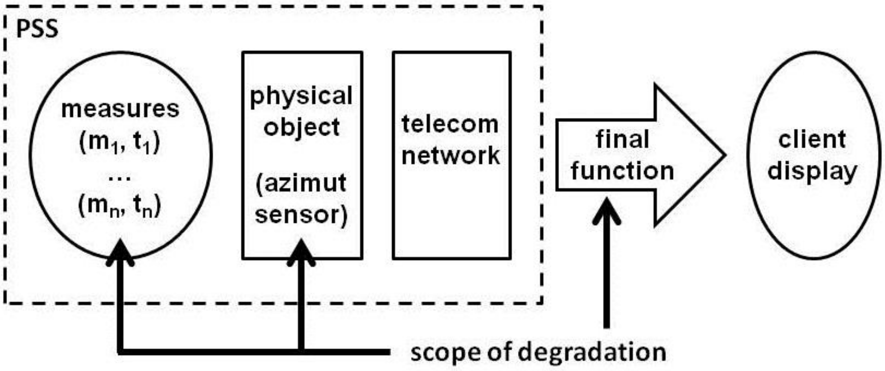

Figure 9. Scope of degradation of the PSS

Table 3 summarises the major evolutions concerning customer satisfaction from the initial market solution to the final industrial solution.

Solution	Strategy	Customer Satisfaction	Source / Reason	Environmental Impact
0		unsatisfied	previous experience of the founder of the SME / too much information	potentially low but with a strong dependency on customer use
1	PSS	unsatisfied	energy consumption too high	high (energy consumption)
2	PSS	satisfied	customer feedback + initial commercial success	medium
3	PSS + degradation	satisfied	customer feedback + commercial expansion	low

Table 3. Customer Satisfaction and Environmental Impacts of the Solutions.

The evolution of customer satisfaction can be explained. From experience, the SME understood that customers often faced problems of dealing with too much information from new sensors. It concluded that customer satisfaction was insufficient and recommended a PSS solution. The SME therefore first prototyped ***Solution 1***, but energy consummation was too high for the applications targeted. The initial industrial ***solution 2*** was a commercial success and customer feedback was positive. The final ***solution 3*** was introduced to the market about a year ago. Although there is no quantitative confirmation as yet, customers have expressed their satisfaction of the expert services despite the degradation of some functionality. Furthermore, commercial expansion has been rapid and currently remains very strong showing that the solution is considered attractive and that customers are satisfied with performance.
Figure 10 shows photos of both industrial products.

(a) Ladybird Sensor® *(b) Greenbee Sensor®*

Figure 10. Sensors for the PSS.

Solution 2 (Figure 10Figure 10a) has aluminium casing and solar panels. ***Solution 3*** (Figure 10b) uses a plastic composite with only one solar panel. Both devices use batteries for energy storage. Both have specialised sensors for measuring chemical pollution (CO2, NOx and O3), noise and temperature.

4.4 Intelligently Degraded Eco-design

The constant evolution of the PSS was achieved by applying the iterative method described above. However, the most radical changes inducing important environmental gains were only possible because the functional degradation in turn allowed partial degradation of some of the components and services in the PSS.

One of the drawbacks of ***Solution 2*** was the high data sampling rate and quality requiring energy for processing and transmission. To resolve this, designers analysed the system. They identified the intermediary products and services that could be degraded, starting with the quantity of data collected, they successively degraded the system. They identified how to transfer less data without deceiving the customers' experience. The microphone was degraded and efforts focused on modifying data processing and compensating degraded data sampling. As a result, less energy was finally necessary in ***Solution 3*** and this allowed designers to change the storage battery to a lighter technology and reduce the solar panel surface. The overall weight of the system was drastically reduced which allowed the use of composite materials rather than aluminium for the casing.

The results of the LCA using EIME software are presented below. The impacts of ***Solution 3*** (Greenbee) are compared to ***Solution 2*** (Ladybird) for 11 environmental categories considering all the life-cycle phases.

The global result is seen in Figure 11. The new PSS has much lower impacts for all indicators except for Ozone Depletion. Improvements between 30 to 90% have been obtained, which can be considered to largely override the degradation of Ozone Depletion.

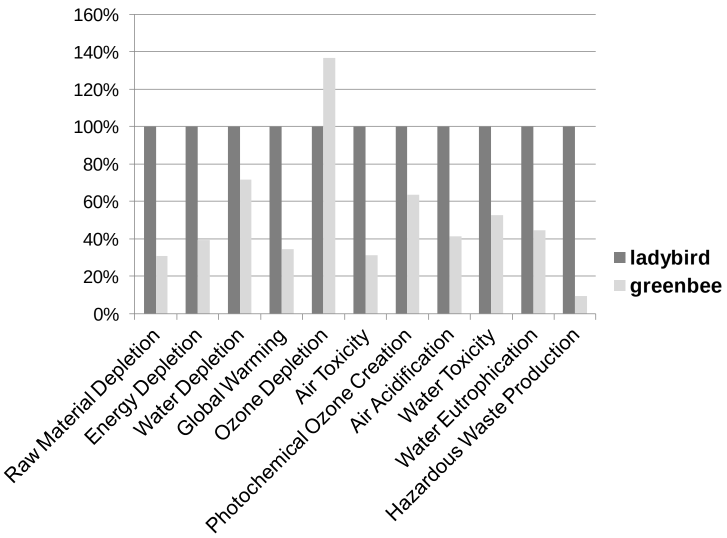

Figure 11. Global Relative Impacts.

Figure 12 studies the effects of changing the casing from aluminium to composite. It clearly shows the environmental superiority of the lighter, composite casing and its mechanical parts for all the impact categories. Gains are over 80% for all the categories of indicators. In ***Solution 2*** the aluminium casing was necessary to support heavy batteries necessary to insure the transmission of lager amounts of information that were finally considered as unnecessary.

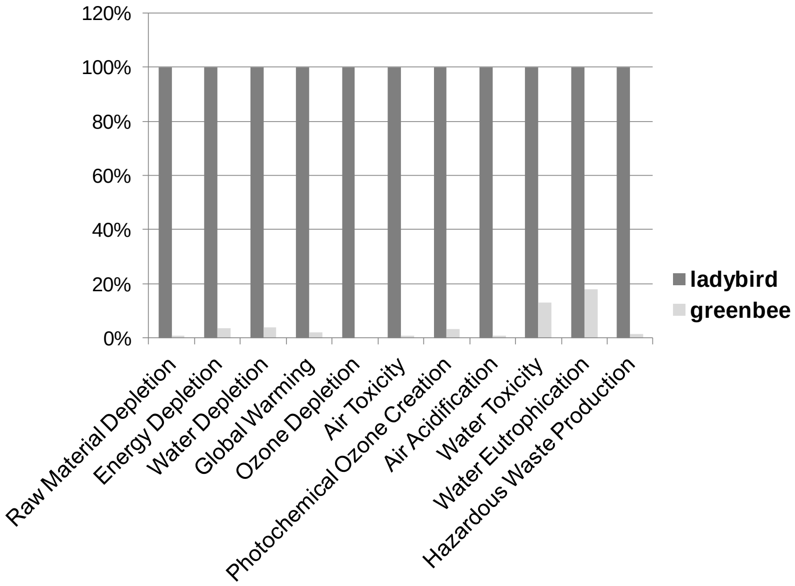

Figure 12. Relative Impacts of the Casings.

The effects of the power block are illustrated in Figure 13. The new power supply is better, showing significant gains, over 30% for six of the indicators. However the lithium battery induces significantly higher impacts, over 30%, for Air Acidification.

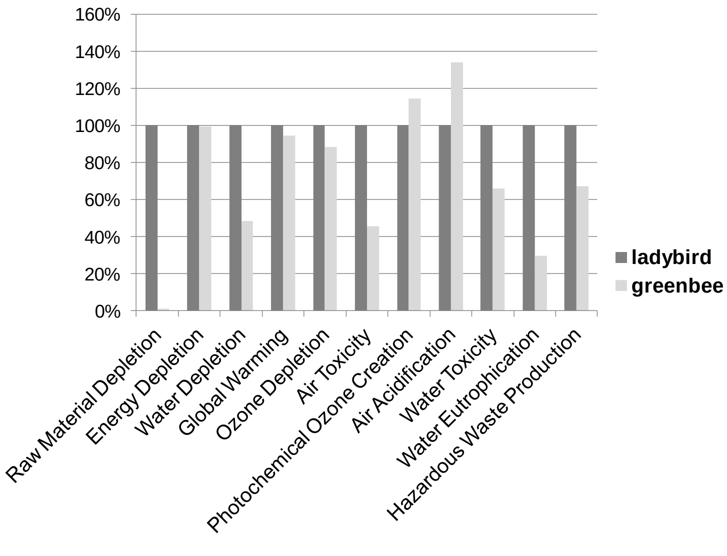

Figure 13. Relative Impacts of the Power Blocks.

A closer look at the electronic devices shows that the improvements were made at the expense of more performing electronic equipment to process the data locally. The denser electronic components display much higher impacts in 7 categories, as can be observed in Figure 14.

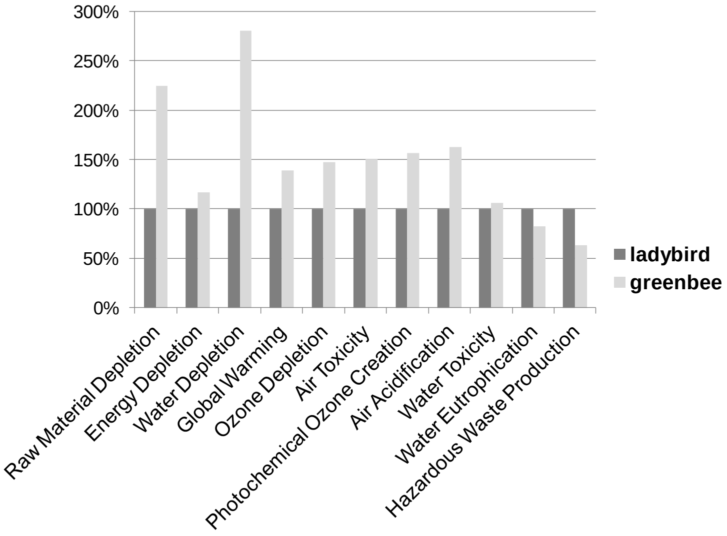

Figure 14. Relative Impacts of the Electronic Components.

5. Discussions and Perspectives

The choice of PSS as the starting point for industrial offerings was initially based on understanding the customers' difficulty to cope with large amounts of information produced by the sensors. Clients normally neither have the capacity, nor the desire, to treat this information in its raw form. Presenting the information with simple colour scales is sufficient to monitor noise, pollution, humidity and temperature in most cases. Actually this first innovative redesign of the PSS was rather conventional because it conserved as much raw data from the sensors as possible to provide good service. Indeed this is often the case given the facility that modern telecommunications have to reap and conserve data. Concern at that time was only to process the data and display the information in a user-friendly way. Technical performance was very high and could easily satisfy customers. Once the confidence established, the SME was able to enter the process of degradation by accepting to loose data and optimise the information, reducing the environmental burden of the offer in the final solution. From its close relations with the customer, the SME was able to understand, identify and analyse the points where degradation was acceptable for the clients. This opened the way for a simpler technical solution reducing the environmental impacts. At this stage technical performance and customer requirements are equivalent.

Finally the important phases of the redesign can be resumed as follows:

1. PSS instead of product (solutions 1, 2 and 3)
2. Degrading sampling rates and communication performances (solution 3)
3. The consequences were less energy requirements and therefore potential environmental gains.

The case study highlights the possibilities of system innovation, degrading the offer while benefiting the environment and maintaining customer satisfaction. The case study simultaneously combines three aspects in the PSS: degradation within the eco-design process; better knowledge of the client; and innovation. That is how it boosts systemic innovation and maintains the necessary level of satisfaction. Degradation alone is not a solution for products or services; it must be considered in a larger context that includes factors such as the customer experience; functional unit and environmental considerations as well as flexibility of the offerings.

The focus of this paper is degradation of technical performance to reduce environmental impacts. This implies negotiation with the users. The SME studied does not dispose of the sufficient means to conduct extensive systematic research on the effects of their offerings. The information they have comes directly from their close relations with the clients who express good satisfaction. This observation is supported by the fact that the business is expanding rapidly and that current contracts prefer the new solution (the old one still exists and could be used, if necessary, in the extremely limited applications such as automobile racing events that require high data sampling rates to detect noise levels of fast moving racing cars).

The concept can be extended to other initial offerings of products, services or PSS, although the final results could be more or less probing. In any case, environmental assessment must be used to confirm the reality of the benefits. The processes that are potentially degradable will probably vary from one case to another, depending a lot on market circumstances. For example, when the principal motivation for pushing the PSS to the market is industry wanting to introduce a new offering, user needs are not well defined. The company proposing a novel offering in the market has more leeway to negotiate. When customer demands pull the market, usage and habits already exist and it is more difficult to change the market.

Customer satisfaction is a dynamic parameter and market demands can change very quickly. It is notable that SMEs with small and flexible structures are well-adapted for converting new ideas into marketable services to be deployed rapidly in changing markets (Lelah et al., 2011). As in the case study, they are probably going to be a driver for this kind of approach.

It may be noted that a similar iterative process as described in this paper (section 4.3) could also be applied to cost or economic considerations. Indeed, replacing the reasoning on customer satisfaction by cost could be used to help resolve tensions between economic and environmental considerations. Identically, replacing the environmental impact by cost could help identify the tensions between economic and social considerations. In this way the process would cover the tensions related to the three poles of sustainable development: economic; social and environment (Lelah et al., 2011).

Finally, negotiating with the clients and tailoring the PSS offer, gives developers a chance to foster good relationships with clients. This may be a way to strengthen the position of companies involved as this kind of service is difficult to copy.

6. Conclusion

This article, based on design considerations treated in current literature and a case study, showed that it was possible and necessary to change paradigms to open new possibilities that improve environmental performances through innovative proposals. To move the economy to an immaterialised one pushes the designer to analyse product and/or service substitutes. It is proposed to balance technical performance degradation and satisfaction as a driver to reach this goal. The case study shows that environmental gains can become significant.

Customers' needs are central in user-oriented product design. Product Service Systems introduce a new paradigm that emphasises this aspect. They push the designer to think further in terms of functions, user expectation and acceptability. From there, redesign not only concerns the product. It is necessary to broaden the scope of eco-redesign to enhance the whole system. A good understanding of the functional unit of the PSS considering life cycles can guide the designer. The PSS is considered through different aspects, especially on user and environmental issues. The different parts of the offer, their relationships and their intermediary and final functions are identified in order to improve knowledge of the service expected by the user and evaluate his perception of the service. The key to success is the understanding of needs in order to maintain long and short term satisfaction. A balance must be found between the satisfaction of needs and environmental aspects. To do this, products and services with different functional units representing the same level of service for users have to be compared.

The innovation processes must be reconsidered at the system level to open new possibilities for solutions substituting products and services. It is necessary to change the reference points. The article shows that the new paradigm of degrading technical performance while maintaining user satisfaction is possible and acceptable in the case studied. PSS can profit from close customer relations to facilitate negotiation with customers.

The case study was used to illustrate these considerations and demonstrate the role of correctly balancing degradation and satisfaction. Further work should confirm this approach and examine cases in other industrial fields in order to develop the conceptual tools and necessary software. In particular, more studies are necessary to pursue the social aspects concerned by degradation. Other design strategies could also be proposed.

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